

lowing way: The tube is kept filled with refrigerant³ to slightly above the level of the silver cup. The bulb of the thermometer is kept slightly above the mid-section so as not to be too near the air entering at the bottom. A preliminary cooling shows the approximate temperature of the dew-point. The cup is allowed to warm up a trifle, and the cooling is then made to proceed very slowly until the slightest possible deposition of dew appears, when the temperature is noted. The cup is again permitted to warm up a little by checking the cooling, but still maintaining a slight flow of air to prevent any too sharp changes of temperature and to keep the liquid thoroughly stirred. A second deposit of dew is formed and its temperature noted. In the meantime a gentle circulation of air in the vicinity of the hygrometer is maintained by means of a common fan. Owing to the small mass and good heat insulation of the instrument the temperature of the cup can be controlled admirably so as to cause dew to deposit and vanish at will and the temperature maintained nearly constant just at the dew-point for several minutes, thus affording several determinations.

If the observation is correctly conducted the difference between the temperatures at which the dew forms and vanishes, respectively, is too minute to be discerned by the thermometer in the liquid; at the same time there is generally an appreciable difference in successive determinations, just as there is a difference in the successive values of the wet and dry-bulb temperatures.

In the Colorado observations made by the writer on and near Pikes Peak, his practise was to make five readings of the dew-point, followed by ten readings on the whirled psychrometer; followed again by five dew-point readings. The sums of these respectively, with the decimal points properly placed, gave the numerical result of one experiment. Nearly 1000 experiments of this sort are incorporated in Ferrel's psychrometric tables as now used by the Weather Bureau. These tables are based on Ferrel's rigorous formula (20), page 249, Annual Report of the Chief Signal Officer, 1886, viz,

$$p = p_1 - 0.000660 P (\tau - \tau_1) (1 + 0.00115 \tau_1) \text{ centigrade,}$$

or,

$$p = p_1 - 0.000367 P (\tau - \tau_1) \left(1 + \frac{1}{1571} (\tau_1 - 32) \right) \text{ Fahrenheit,}$$

instead of his approximate expression

$$p = p_1 - 0.000660 P (\tau - \tau_1) \left(1 + 0.00115 (\tau - \tau_1) \right) \text{ centigrade.}$$

IMPROVEMENTS IN SEISMOGRAPHS WITH MECHANICAL REGISTRATION.

By C. F. MARVIN, Professor of Meteorology. Dated May, 1906.

About a year ago the writer began a series of experiments with a view to making improvements in seismographs such as are employed for the absolute or quantitative measurement and registration of the motions of the ground during earthquakes, especially in those instruments in which the registration is effected mechanically by a stylus tracing its record upon smoked paper.

The work has progressed rather slowly and with many interruptions incident to the discharge of other engrossing duties, and much still remains to be accomplished before we can feel assured that our seismograms are faithful reproductions in detail and to scale of the actual motions executed by the piers that support the instruments. Certain improvements, however, have now been tested so fully and with such satisfactory results, and the devices may be so easily attached to practically any form of seismograph with mechanical regis-

tration, as to warrant this short account of the work thus far accomplished.

Early in 1903 a set of the Bosch-Omori horizontal pendulums, with mechanical registration, were procured for the Weather Bureau at Washington, D. C., and one of these instruments at once installed. Owing to the lack of a suitable place of exposure, the other pendulum was not set in operation until July, 1905, and then only in a temporary location. More recently, however, both instruments have been reinstalled in a new location under conditions which are quite satisfactory, although still subject in a slight degree to the influences due to the immediate environment. The improvements about to be described have been applied to these instruments, one of which, in its original form, is shown in figs. 1 and 2, and was fully described in the MONTHLY WEATHER REVIEW for June, 1903, Vol. XXXI, pp. 271-275.

The steady mass C is considered generally to remain at rest during the earthquake. The forked short end of the lever L , fig. 2, engages the delicately pivoted pin f forming part of the steady mass C . This point of the lever therefore remains at rest. The motion of the ground is communicated to the lever at its pivot d , carried in the massive yoke piece G , which in turn is firmly secured to the ground or pier. It results from this disposition that lateral relatively quick vibratory motions of the ground will be registered in a magnified fashion as a sinusoidal curve by the long end of the lever L tipped with the stylus as shown enlarged at S , fig. 2. Assuming the reader to be already familiar with the main features of the operation of seismographs we shall proceed at once to the discussion of one of the chief sources of errors in these instruments, namely, friction. The steady mass of the seismograph, if slightly disturbed, will in general be very soon brought to rest by the unavoidable friction in the joints of its mechanisms. On the other hand, during an earthquake this same friction tends likewise to set the mass in motion. Indeed, very small earthquakes often fail to be recorded at all because the friction at the joints of the recording stylus in scratching off the soot literally forces the steady mass to move exactly with the ground, so that no record is obtained. The elimination of friction to the utmost degree is therefore of the greatest importance. Another source of error in the Bosch-Omori instruments that seemed to cause the loss of records of the very small vibrations was in the use of the forked end of the lever L and the pin f . The width of the forked opening could never be adjusted to fit the pin properly. There was always a little lost motion at this joint, or when the pin fitted exactly, the friction was excessive. In setting about to improve our instruments in this respect, one side of the forked arm of the lever was cut away entirely, and a very delicate hair spring of a watch was fastened to the pivot of the lever L so as to cause the short end of the lever to bear very gently against the pin f of the steady mass. The tension of the hair spring was adjusted so as to be just enough to easily scratch the soot on the record sheet. By the new arrangement the stylus is moved in one direction only by the force of the spring, whereas motion in the opposite direction is caused by the direct push of the pin f . This alteration led at once to three important discoveries.

(1) *Increased sensitiveness to short-period tremors.*—The instrument was now found to record minute short-period vibrations of the ground and pier to which previously it had never been in the slightest degree sensitive. The rapid driving of vehicles along an asphalt street about 90 feet distant caused a perceptible thickening of the trace, whereas a large record was made every time a wagon passed over a cobble paved private way only about 30 feet from the pier upon which the pendulum had been temporarily installed for the purpose of this study.

(2) *Improved method of marking time.*—The second valuable

³ The writer finds Squibb's sulphuric ether about the best.

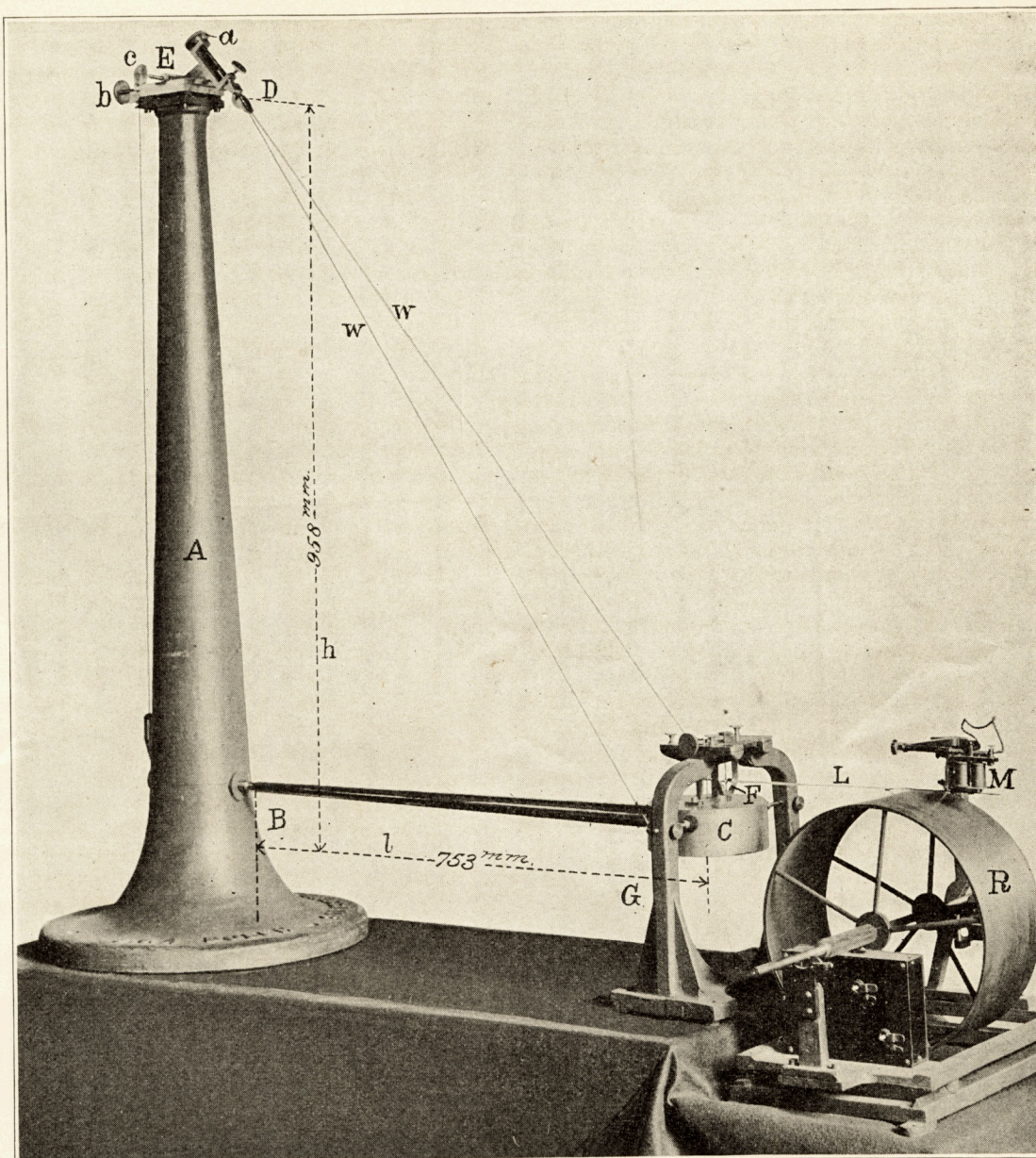


FIG. 1.—Bosch-Omori horizontal pendulum seismograph at Weather Bureau.

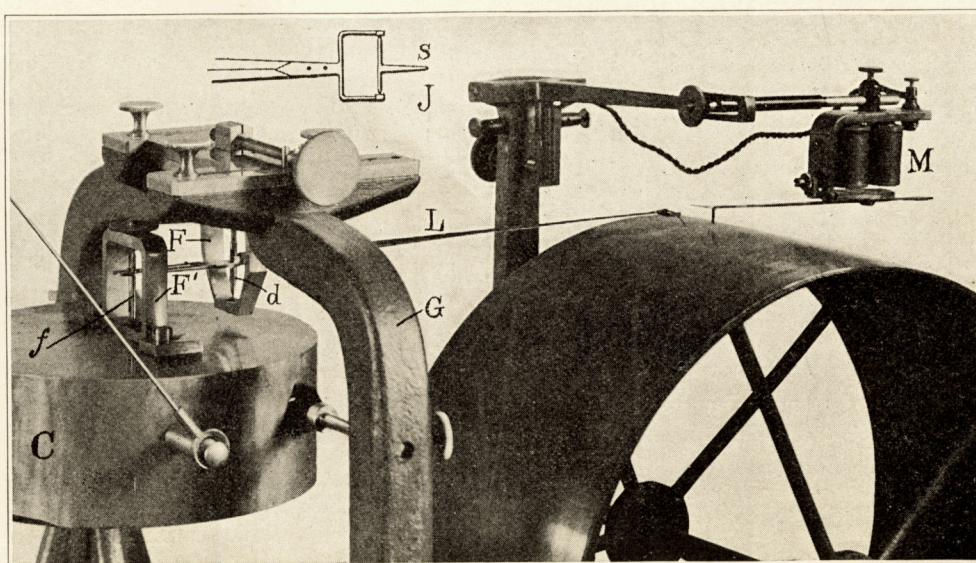


FIG. 2.—Recording and time-marking devices; original form.

fact discovered was that a very slight rap or blow delivered anywhere against the pier, or especially against the yoke piece *G*, would cause the lever *L* to momentarily recoil or kick away from the pin *f*. This provided a long desired method for causing the stylus to mark its own time on the record sheet instead of depending upon the separate time ticker *M* originally supplied. That is, it was found that by simply attaching the magnet *M* anywhere upon the yoke piece *G*, every snap of the armature against the poles of the magnet sufficed to make an excellent time mark on the record. Those familiar with these instruments know how impossible it is to determine accurately the time correction between the time ticker *M* and the point of the stylus, when the time is marked independently of the stylus.

(3) *Great reduction of friction by vibration.*—The third and perhaps the most interesting discovery was largely the result of accidental circumstances. It was noticed that at certain times now and then each day the lines of the seismographic record were visibly thickened in a comparatively uniform and continuous manner. This was soon traced to the influence of a small electric motor used in the machine shop in a distant part of the building, which set up minute short-period tremors in the building that were communicated to the seismographic pier. That is to say the pen lever was in a continual state of minute motion which was just easily visible to the unaided eye and which showed on the record simply by the thickening of the line. The valuable feature in connection with this observation, however, was that this vibratory motion reduced the effective friction at the pivots of the lever and the point of the stylus to only a small fraction of its amount without the vibration. I saw at once that it would be very easy to induce vibrations artificially and continuously by simple electrical devices. The steady mass and yoke piece of this instrument were at this time inclosed in an improvised pasteboard box to cut off air currents, and I found artificial vibrations of sufficient intensity could be induced by simply laying a small electric call-bell on the pasteboard box. The bell itself was removed and only the armature and clapper allowed to vibrate with a low humming sound and very feeble battery power (not exceeding one-tenth ampere). The results of these discoveries as affecting the records are reproduced in figs. 3 and 4.

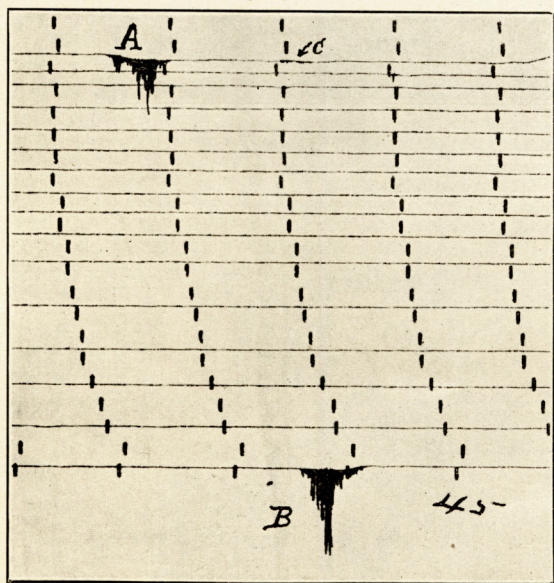


FIG. 3.—Portion of record of August 18, 1905.

A, B, are rapid kicks of the pen lever, caused by the passage of a wagon over cobblestone private driveway nearby. At *C* the line is visibly thickened by the minute tremors due to a light wagon driven over a smooth concrete pavement about 90 feet distant.

Lever L, and magnification.—The magnification of the record of the seismograph depends mainly upon the relative length of the long arm of the lever *L* and the distance from the pivot *d* to the pin *f*. The former can be determined very easily, but the writer has been repeatedly annoyed by the difficulty of ascertaining properly the distance from *d* to *f*. Even if this distance is once carefully determined yet changes from time to time are unavoidable and it seems vastly better construction to provide the short arm of the lever with a definite adjustable point that makes contact with a smooth projecting surface on the steady mass. By properly adjusting the position of the point the magnification can then be set at any desired amount and remains invariable. At the same time increased facility is secured in adjusting the position of the lever.

Stylus.—It is very desirable to be able to determine pretty closely the pressure of the contact of the stylus on the paper. For this purpose and in order to enable the stylus to return upon the record sheet when it is carried beyond the edge of the cylinder by large earthquake motion, the writer adopted the form of stylus shown in fig. 5 as it appears in its writing position in the end of the lever.

The pivot *f* is made by breaking off a bit of a fine sewing needle about .02 inch diameter and shaping the ends to fine sharp conical points. The stylus itself is made of a piece of fine aluminum wire, about .013 inch diameter; other kinds and sizes of wire have been tried, but the above is preferred. One end of a straight piece of this wire is carefully filed to a cone point of from 50° to 60°, fairly sharp but perfectly smooth and even. The wire is then given one turn around the pivot *f*, to which it is cemented by melted shellac or suitable strong wax. The long arm with the point slightly bent downward is made about one inch long. The short end must be cut off short enough to permit the marking point to be lifted from the record and turned over out of the way. A drop of wax, *d*, melted onto the short arm suffices to balance the stylus so as to give the desired pressure. This at first was computed from the known weight of the wire per unit length and other dimensions, but the process proved too tedious and I finally improvised a very simple balance for the purpose, composed of a piece of aluminum wire wrapped once around a bit of a steel needle to which it is cemented. Knife edges are not essential as the needle axis rolls on supporting straight edges very nicely. One end of the wire is flattened and a slight dimple or prick mark made at a measured distance from the axis. A bit of wire flattened at one end is hooked into this for a scale pan and the pen point stepped into the pan while the axis is held in a suitable fork as shown in fig. 6. Equilibrium of the balance is secured by a two or three milligram rider and its distance from the center measured. The pressure of the stylus is measured always with the long arm horizontal. The stylus is then allowed to swing free on its axis and the angle of depression ($=\sigma$) observed. In this position the pressure at the point would be zero. The pressure in any other position may be found by the equation

$$p = \frac{w}{\sin \sigma} \sin \theta$$

where θ is the angular amount the needle is lifted from its pendent position, w is the observed pressure when the needle is horizontal, and σ is the angle of depression of the needle when poised free. A pressure of over one milligram is generally greater than necessary. A half milligram is, however, scarcely sufficient, except for very fine lines on thinly sooted paper.

The position of the short arm of the stylus, as seen in fig. 5, is such that if the stylus passes beyond the edge of the record cylinder the point drops only a slight distance below the level of the surface of the drum. The edges of the drum have been

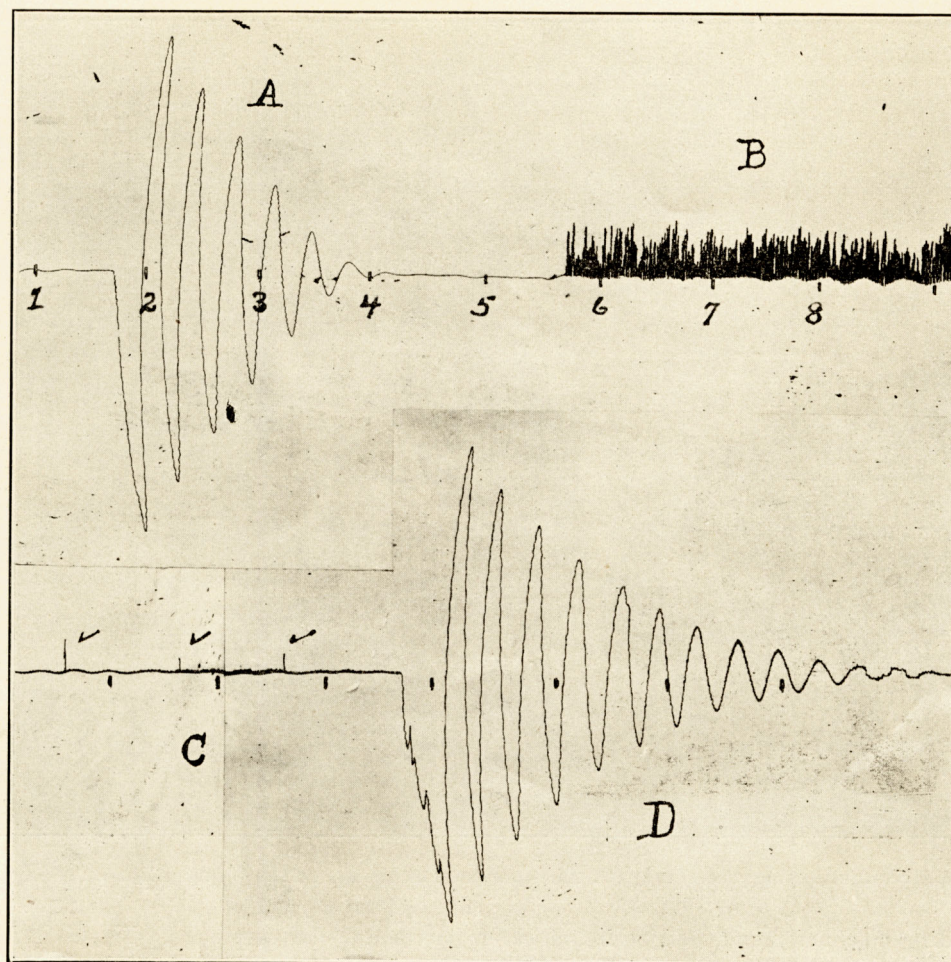


FIG. 4.—Showing effects of improved mounting and vibrator.

Trace A, normal action of instrument without vibrator. B shows rapid lateral pen strokes due to exaggerated influence of vibrator, when adjusted to synchronize closure with movement of pen lever. C, similar effect on relatively minute scale, amounting simply to slight thickening of line. D is tracing drawn by pen under influence of vibrator. The more numerous waves in D, as compared with A (4 to 8), show greatly diminished friction due to vibrator.

The ordinary time marks are shown at "1," "2," "3," etc. The time strokes made by the pen itself are shown by the check marks at C.

reinforced and beveled beyond the margins of the paper so that when the stylus, after having passed beyond the edge, returns, the point first strikes on this beveled formation so as to lift the point up onto the cylindrical surface. The margin of the paper, even if closely fitting the drum, sometimes obstructs the return of the pen a little, especially if thick paper is used; but we have found this arrangement of the pen to operate admirably in great earthquakes. Little or no loss of record occurs when the pen passes off the sheet.

The writer is strongly opposed to the use of stops limiting the relative motion of the steady mass and pen levers except at points entirely outside the limits of the record sheet. During heavy earthquakes the steady mass may remain sensibly at rest. If, however, stops are set with a narrow limit of motion, the large displacement of the ground causes these stops to butt into the steady mass and set it into violent motion, which subsides only after a considerable time, thus rendering a large portion of the record valueless. The simple passing of the pen off and on the sheet over the beveled edge of the cylinder may cause some loss and errors in the record, but the steady mass is disturbed only to a minimum extent.

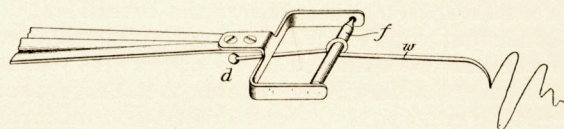


FIG. 5.—Aluminum wire stylus in writing position.

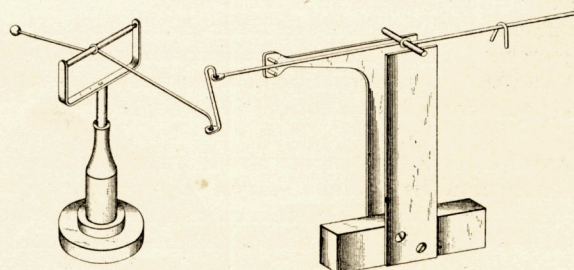


FIG. 6.—Improvised balance for weighing the pressure exerted at the point of pen.

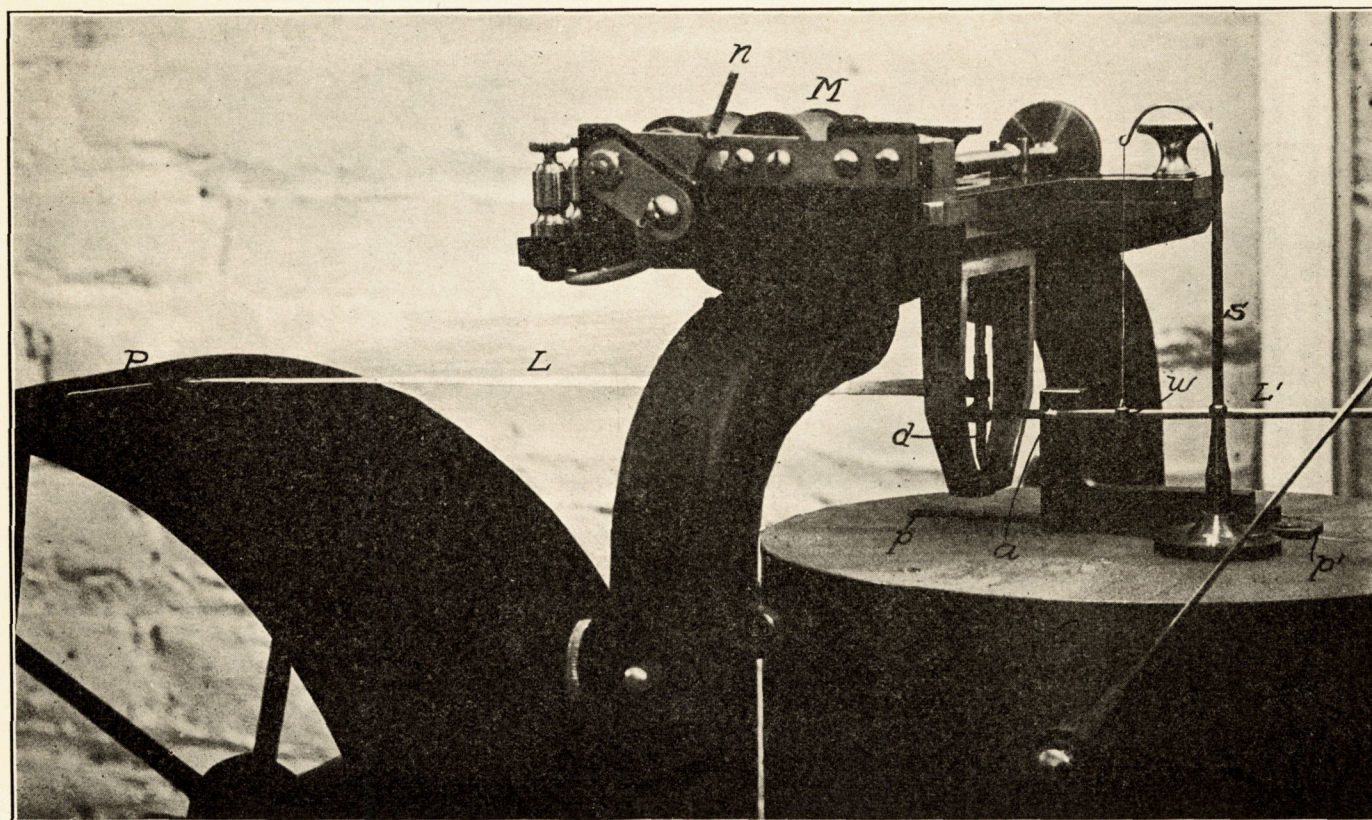


FIG. 7.— Improved multiplying, recording, and time-marking mechanism on the Weather Bureau seismograph.

The details of the recording mechanisms of the Bosch-Omori seismograph in its improved condition are shown in fig. 7. The multiplying lever LL' is carried as before on the sharp pointed, pivoted axis d in the adjustable stirrup F . The latter is rigidly secured to the supporting pier by the massive yoke piece G . The original forked, short arm of the lever, as shown in fig. 2, has been replaced by the extension L' , which consists of a slender steel rod, the weight of which very nearly balances the whole lever on its axis.

It may be well to state here that the following conditions require to be satisfied in the design and construction of the multiplying levers of the seismograph:

(a) In order to avoid unnecessary friction at the pivots, as well as for other reasons, the mass of the lever must be the minimum consistent with adequate strength and stiffness.

(b) The lever must be balanced on its pivots for two reasons: First, because the friction will, in general, then be less; second, to render the lever neutral to earthquake motion, for if not balanced, it would tend to oscillate about its own center of percussion when subjected to earthquake motion and thus introduce a complication in the behavior of the seismograph that is absent when a balanced lever is used.

(c) The moment of inertia of the lever should be a minimum, so that it may respond promptly and accurately to short-period vibrations and so that the reaction at the steady mass required to produce the forced oscillations of the lever may be a minimum.

These requirements are incompatible in certain respects, and some compromises are necessary. A very light lever of minimum mass and moment of inertia can easily be made of adequate strength, but it will not be balanced; the long arm will be too heavy. If now we balance by adding a heavy counterpoise close to the axis, we get a smaller moment of inertia than if a lighter counterpoise at a greater distance

from the axis be employed. In this latter case, however, the friction is less. It can easily be shown that with ordinary light multiplying levers and the relatively slow-period motion of ordinary earthquakes the second requirement under (b) and also that under (c) are relatively unimportant details, and the writer has found that the form of lever shown in fig. 5 exhibits less friction at the pivots and is otherwise better than heavier levers of less moment of inertia. Moreover, such a lever is found to recoil better, that is to kick off in the desired manner under the action of the time-ticker magnet M , so as to produce the time marks on the record sheet. The lever is not quite balanced. The extension L' is not exactly on the line of centers, but is thrown off slightly so that the pointed end of a small projecting pin attached at a may fall on the line of centers. This lack of balance appears to be necessary to give a large recoil with a very light tap of the magnet, but I have not yet had an opportunity to examine this point fully.

The projecting pin at a rests very lightly against the angle F' , which is securely attached to the steady mass C , but may be adjusted thereon by sliding upon the metal strip pp' . The portion of F against which the pin a presses is faced with a thin plate of glass.

In order to keep the pin a pressed against the steady mass, I now employ the small weight w , hung by a silk fiber from the small adjustable stand s , which rides on the steady mass.¹ The weight w should press against the lever L' as close as

¹ This is simply an elegant little device for the purpose, producing, as it does, a practically constant contact pressure over a wide range of positions of the lever L . It is quickly adjustable and invariable with time or change of temperature. I borrowed this idea from a new Bosch-Omori seismograph received at the Weather Bureau a few months ago, after the other improvements described in this paper had been incorporated in one of our pendulums. I regret that I do not know the name of the real inventor of this very useful device.

practicable to the point *a*. It was set at one side in the photograph to show more clearly.

I first employed a spiral spring on the axis *d* to hold *a* in contact with *F'*. The pressure of contact is not constant with different angular positions of the lever, and it is not easy to adjust such a spring minutely. I also tried a slightly unbalanced lever with the axis *d* tilted a little, in the proper way, to make *a* bear slightly against *F'*. This hardly admits of easy variations and nice adjustments. I considered, but rejected, the plan of maintaining *a* and *F'* in slight contact by mutual magnetic attraction. The contact, once broken, would not be automatically restored, which is a necessity in the process adopted for making time ticks.

The aluminum wire stylus, with its wax counterpoise, is clearly shown at *P* and *e* in the picture; the bevel on the edge of the cylinder is very imperfectly shown, however.

The ratio of the lengths of the two arms of the lever is at present set at 15 on this instrument. It is sensibly invariable, despite any adjustments which may be made of either *F* or *F'*.

Vibrator and time ticker.—This attachment is shown at *M* and is made over from the magnets of an ordinary small electric call bell. The magnets are rewound to a resistance of from 12 to 15 ohms. The bell and striker are dispensed with. The whole device is mounted on a stud that is simply fitted closely into a hole drilled into the yoke piece *G*. The two terminals of the coils are brought out directly to two binding posts. A third post is put in connection with one terminal through the vibrator. A single dry cell (voltage 1.4) is put on this circuit through the vibrator and causes the armature to vibrate with a low musical hum. A little lever, split so as to embrace the free portion of the contact spring on the armature, serves to alter the period of vibration somewhat.

It seems that very feeble action of the vibrator is able to set up microscopic tremors in the massive yoke piece, *G*, sufficient to keep the whole lower arm, *L*, in sustained movement, so that friction is greatly diminished and other desirable effects produced, as has already been explained.

In order to mark time it is necessary, or at least preferable, to stop the vibration of the armature for a second or two, then to cause the armature to strike a sharp blow by sending, for a fraction of a second, a current of proper strength directly through the magnet. On the instruments at the Weather Bureau the time is marked as follows: At the 30th second of each minute the standard time-keeping clock electrically releases momentarily the train of a secondary clock in the seismograph room. A slight movement ensues and cuts off the current to each vibrator. After exactly two seconds the secondary clock is again released momentarily and this time a strong current is sent momentarily through all the magnets joined in series, thereby causing the recording levers to simultaneously produce time marks. As the cycle of actions is completed on the separate instruments the strong current is cut out and the vibration again started. The apparatus seems more or less complicated in the description, but in reality it is relatively simple enough.

Smoking flame.—In smoking the record sheets the recording cylinder is mounted on the iron support furnished by the manufacturer. Over this is an ample iron hood connected directly with a chimney flue to carry off the excess smoke. The best form of lamp I have thus far tried is made with a flat lamp wick about 8 inches long by $1\frac{1}{2}$ inches wide. A piece of tin a little longer than the wick and not quite so wide is bent longitudinally through the middle into a U-formed trough. The ends are closed by pinching together, or otherwise, and the whole is secured to a plate or other device to make the open edge stand up. The wick is folded longitudinally through the middle and inserted in the trough with the free edges projecting slightly and equally above. Kerosene or other oil is applied to the wick from an ordinary machinist's so-called

"squirt can". In order to lessen the tendency of the flame to flutter and burn unevenly, I set up beside it, and about one-half inch or less distant, a flat plate of stiff sheet iron. This rises beside the flame to within a half inch or less of the recording drum. The ascent of heated air across this plate produces a more even flame than without the plate, which, moreover, I think tends to chill the flame and increase the volume of soot.

Paper and varnish for records.—The writer has found serious objections to the glazed paper commonly furnished and employed for record sheets, because it is too opaque to readily give photographic prints of records. It tears easily and the glazed coating is greatly affected by moisture, often causing the paper to curl up in the most unmanageable fashion. Finally, the soot coating very easily flakes off the glazed surface whenever a record is handled much, often defacing it in the most serious manner. A thin, smooth bond paper is vastly superior in point of durability, transparency, etc., but the lines are not quite so clearly visible by reflected light, as in the case of records on glazed paper. The sheets, however, remain flat and are much easier to file away.

The writer uses a celluloid varnish made as follows:

Thirty grams of transparent sheet celluloid is cut into narrow strips, which are then sharply bent at many points and thus crumpled up. These are placed in a large bottle (not less than two liters); 300 cubic centimeters of acetone is then added. After some hours with occasional shaking, a thick, viscous solution is formed. From 1500 to 1800 cubic centimeters of amyl acetate is then added and thoroughly mixed. A small portion of this is poured into a shallow tray, the top edges of which are ground true and flat in order that the tray may be closed practically air-tight by a small plate-glass cover. Such a tray, I find, prevents any appreciable waste of varnish and loss from evaporation. Sheets are varnished only on the smoked surface by passing it in contact with the liquid in the tray, while the sheet is held by the hand at each end so as to form a deep J-formed loop. The sheet is drained for a moment over the tray and dried while stretched horizontally between hooks, with the face downward to keep off dust.

The foregoing details relate to improvements that may, perhaps, be adapted to almost any seismograph with mechanical registration. I desire, in a second section of this paper, to discuss in a general way the dynamic characteristics of the more important seismographs now employed, with a view to indicating or contrasting their merits and defects.

WEATHER BUREAU MEN AS EDUCATORS.

Mr. George Reeder, Columbia, Mo., under date of May 17, 1906, referring to his regular course in the University of Missouri, states that the course included twenty lectures, and, as briefly described in the University catalogue, embraced the following subjects: (1) The earth's atmosphere—its composition, temperature, pressure, and circulation—dew, frost, clouds, rainfall, cyclones, thunderstorms, and tornadoes. (2) Weather and climate. Instruction under this second head included, among other topics, a discussion of the distribution of temperature and precipitation, the influence of winds upon climate, climate and weather, climate and health, comparison of climatic conditions at well-known health resorts of the world, weather records and health statistics, weather forecasting.

Charts, blackboard diagrams, photographs, and lantern slides were used to demonstrate the lectures; observations, written exercises, and laboratory work were required. The class consisted of nine students—eight medical and one agricultural. (Medical students are now required to take the course.) Each member of the class displayed great interest in the entire course, and the final examination was sustained in a very creditable manner.